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TITLE: SUMMARY DESCRIPTION OF A METHOD OF OPTIMIZING CAMBER SURFACES FOR WING-BODY COMBINATIONS AT SUPERSONIC SPEEDS

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INTRODUCTION

A variety of promising approaches to the theoretical solutions of supersonic wing-body problems have been studied by researchers for many years. From this background, a method of influence coefficients based on linear theory for lifting wings has been developed for practical use by Boeing. This method was extended into a digital computer program for the analysis or design of the wing of a supersonic wing-body combination; the program includes the effects of body interference. The work was performed under NASA Contract NAS2-2282 during a one-year period.

This summary is one of two reports written to describe the resulting program's capability. The other report is in two parts (references 1 and 2) Boeing Document D6-10741, Part I, A Method of Optimizing Camber Surfaces for Wing-Body Combinations at Supersonic Speeds — Theory and Application; and D6-10741, Part II, A Method of Optimizing Camber Surfaces for Wing-Body Combinations at Supersonic Speeds — Digital Computer Program Description. Part I describes the aerodynamic theory underlying the computer program and the types of problems it can solve, while Part II provides the details necessary for understanding the digital computer program.

The intention of this summary is to introduce the work performed under the contract and put the results into context. Details of the computer program, how it is used, and the theory behind it are contained in the other two reports.

DESCRIPTION AND SCOPE

The result of this research study is a method for aerodynamic analysis and design of supersonic airplane configurations. A procedure is included in this method for optimization of the wing camber surface for a complete wing-body configuration with a specified body shape. This optimization can be achieved within constraints of wing lift and pitching moment.

The method is programmed in FORTRAN IV for solution on the NASA-Ames direct-coupled IBM 7040/7094 computer system. Extensive geometric processing has been included in the program to minimize the amount of preliminary work necessary to prepare a problem for solution.

Several sample cases are documented (reference 1) for illustrating program use and for comparison with other theories and experimental data to validate the accuracy of the method. It was considered outside the scope of the work to evaluate optimization results by comparison with experimental data. However, the sample optimization indicates that the computer program produces results that confirm experience.

STUDY OBJECTIVES

One of the objectives of this study was to extend the capability of the digital computer program developed by Boeing for computing the supersonic influence of wing-body interactions. The resulting program was to be capable of analyzing given configurations to determine pressures on the wing and body and to integrate these pressures to determine the corresponding aerodynamic forces and moments. Another objective was the optimization of the wing to minimize drag, with the body shape specified and with constrained lift and pitching moment. Both of these study objectives were fulfilled satisfactorily.

THEORY

The method of aerodynamic influence coefficients is used to calculate the pressures, forces, and moments on arbitrary wing-body combinations at supersonic speeds, and to predict the optimum camber surface of the wing in the presence of the body. In this method, the wing and body are represented by a large number of singularities located in the plane of the wing, on the surface of the body, and along the body axis. It is assumed that the flow perturbations resulting from this system of singularities are sufficiently small so that equations governing the flow can be linearized without the introduction of significant errors.

The velocity components induced by each elementary singularity are calculated at specified surface control points. The boundary conditions of tangential flow are satisfied at each control point, and the resulting system of linear equations is solved for the unknown singularity strengths.

In actual practice, the singularity strengths required to satisfy given boundary conditions are not solved in a single step. Boundary conditions corresponding to wing thickness, body thickness, and body camber and incidence are separated, and the strengths of the specific singularities used to satisfy them are determined independently. In the final stage of the calculation, these individual solutions are combined by linear superposition, and any residual interference effects are satisfied, together with the wing camber and incidence boundary conditions, by surface distributions of singularities on the wing and body.

The wing and body are subdivided into a large number of small panels, where, depending on how panel boundary conditions are specified, each panel has one or more singularities associated with it. Two types of singularities are specified for each wing panel. First, a surface distribution of vorticity corresponding to a unit pressure difference across the panel is used to simulate the lifting effects of camber, twist, and incidence; and second, a surface distribution of sources simulates the effect of wing thickness. It is shown that the boundary conditions on the surface of the wing can be completely satisfied by these two independent singularities.

The body is represented by line sources and doublets distributed along its axis to simulate the effects of body thickness, or camber and incidence, respectively. In addition, the surface of the body is subdivided into panels in the region of influence of the wing-body intersection. These body panels of surface vorticity are used to cancel the interference of the wing on the body.

If the shape of the wing camber surface that will yield the minimum drag for the wing-body combination under specified conditions of lift and pitching moment is desired, a slightly different method is used to solve for the strengths of the singularities. The drag of the complete configuration is expressed in terms of the unknown singularity strengths. The values of the singularity strengths that will result in minimum drag consistent with the lift and pitching moment constraints are determined by application of the method of Lagrange multipliers to the system of equations so formed. These values may then be used to calculate the optimum shape of the camber surface and, as before, the corresponding pressures, forces, and moments acting on the configuration.

RESULTS

Three of the problems studied in detail during program development are reviewed here as typical results. The first problem was the load computation for a wing alone with specified planform, thickness, camber, and twist. The second problem was the computation of wing and body load distributions for a configuration with an untwisted, cambered wing. These problems checked program accuracy; their geometry and experimental pressure distributions are known. Wing optimization (of the second problem configuration) with constrained lift is given as a third solution. These problems are shown in figures 1 through 3.

Wing-alone results, figure 1, compare the lift curve, drag polar, and pressure distributions with experimental data from reference 3. Viscous effects and aeroelasticity probably account for the experimental data's lower lift curve slope and less open polar than the theoretical curves. However, agreement of the pressure distributions and the force data is acceptable.

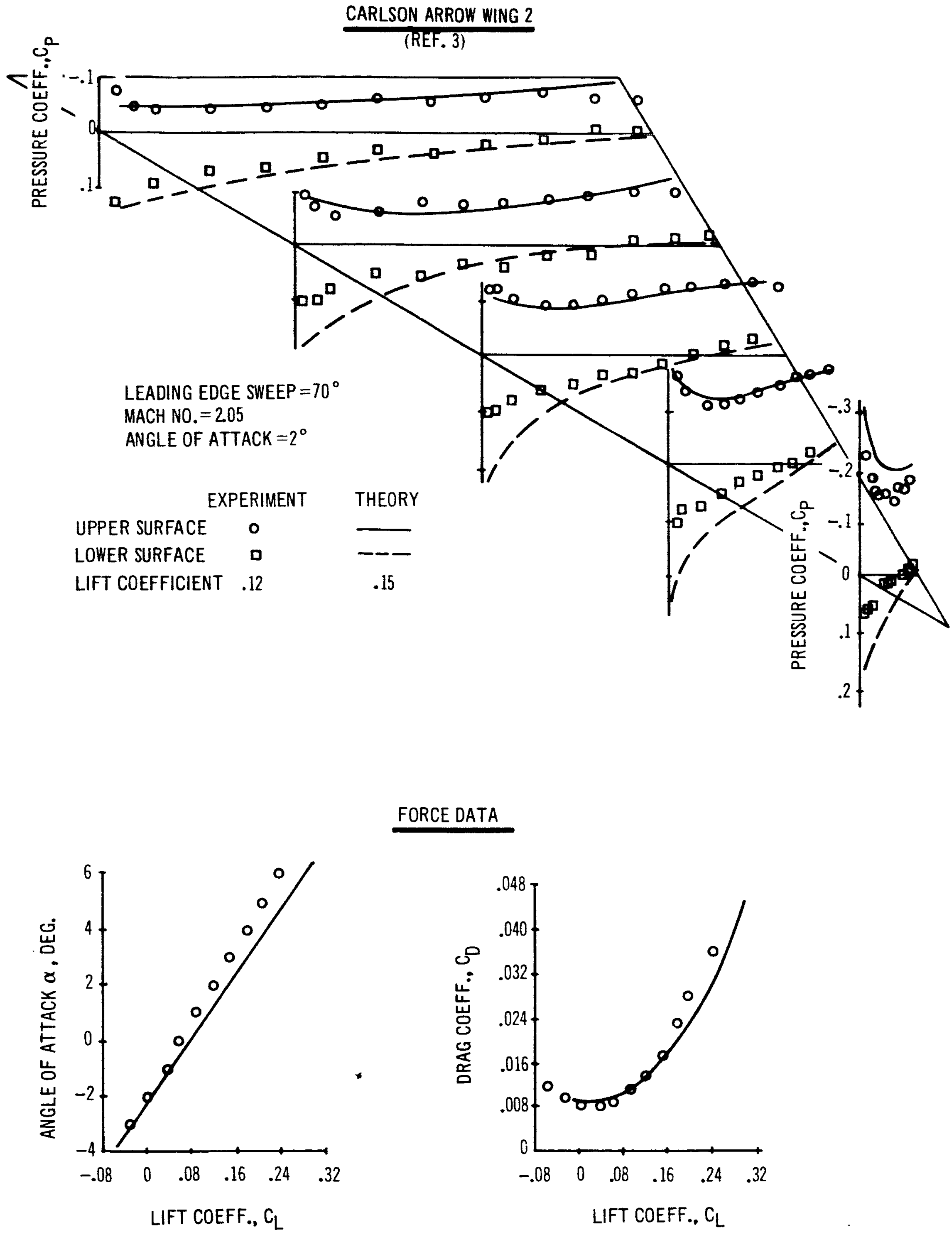


FIGURE 1 COMPARISON OF WING-ALONE RESULTS WITH EXPERIMENT

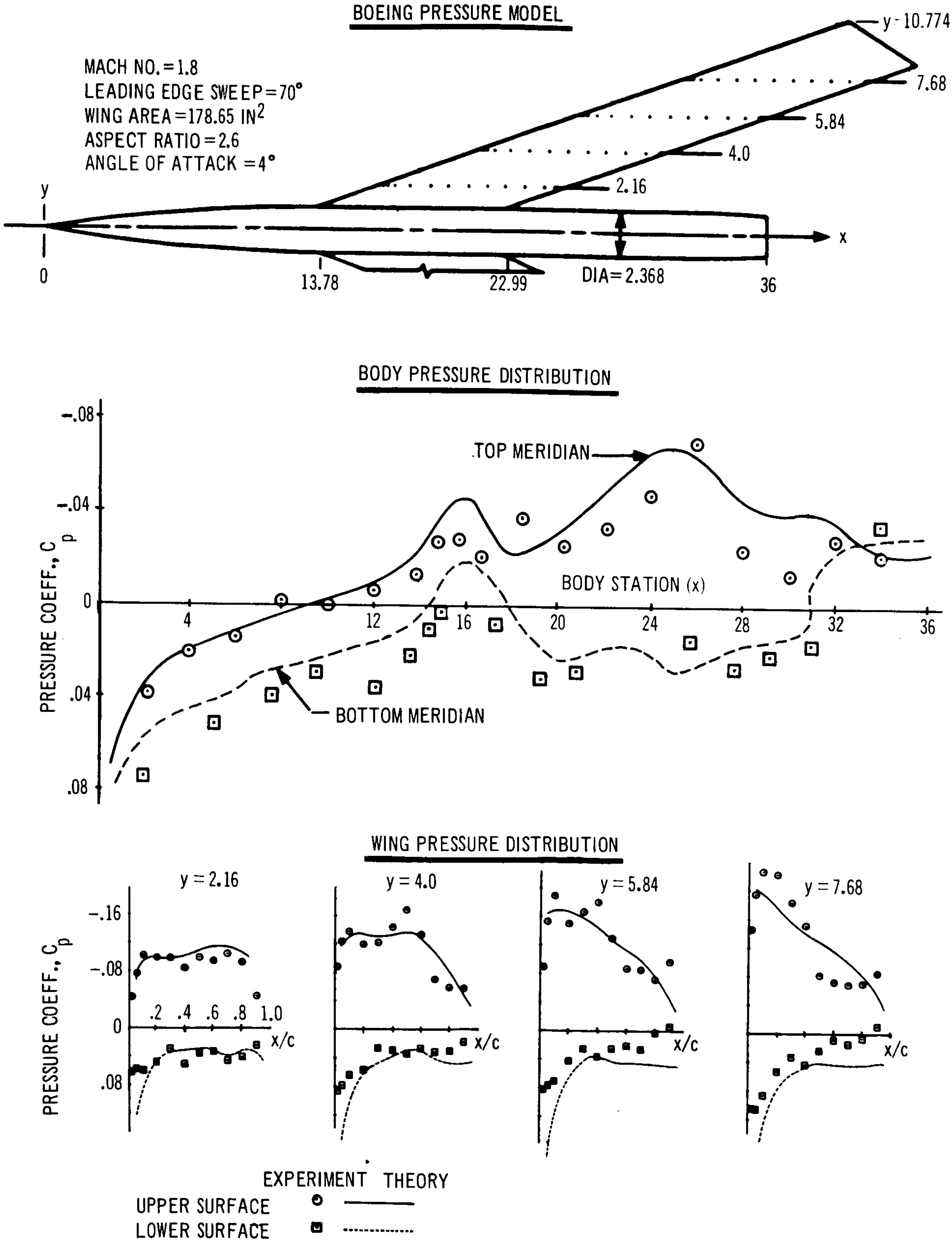


FIGURE 2 COMPARISON OF WING-BODY RESULTS WITH EXPERIMENT

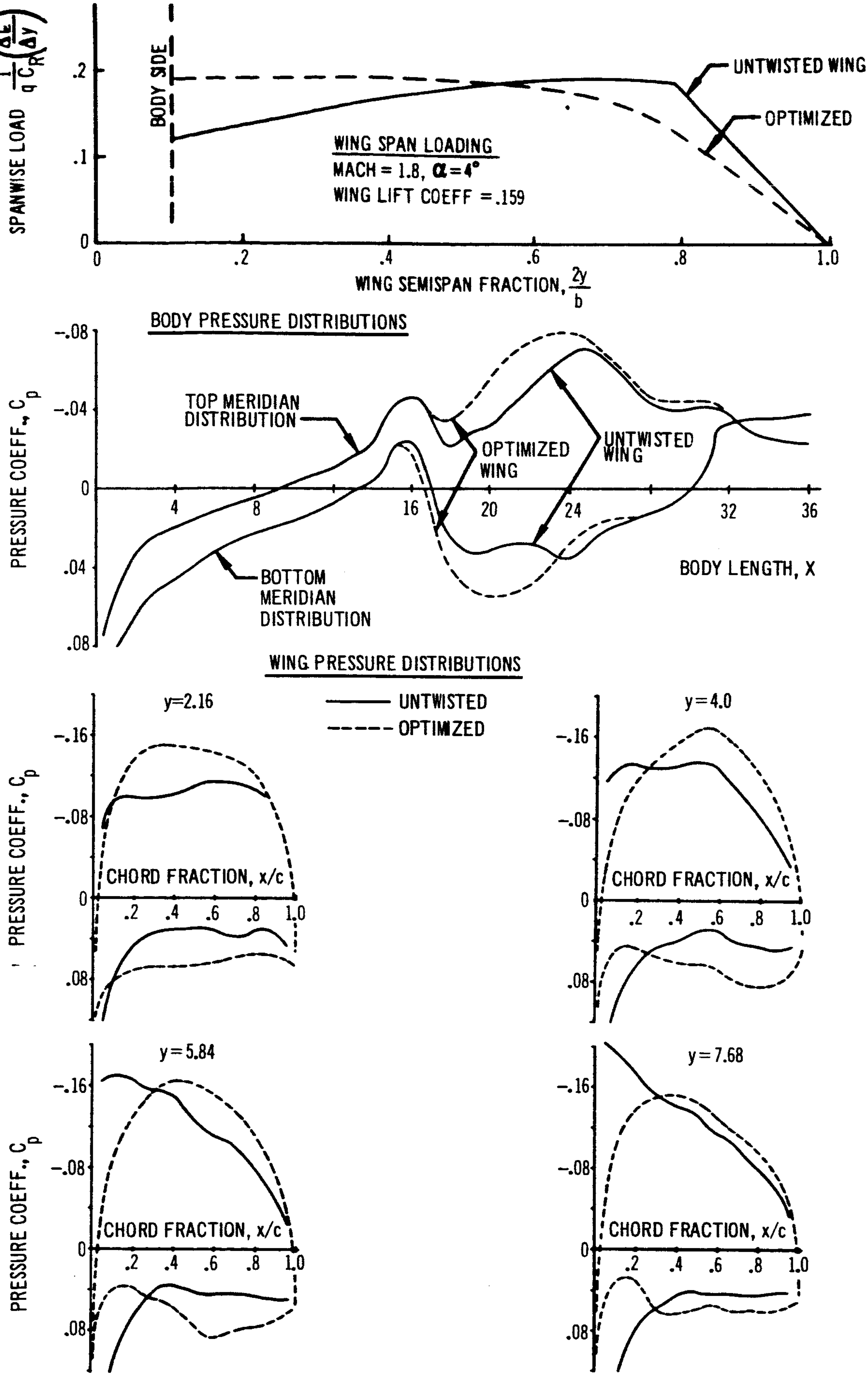


FIGURE 3 COMPARISON OF UNTWISTED AND OPTIMIZED DISTRIBUTIONS

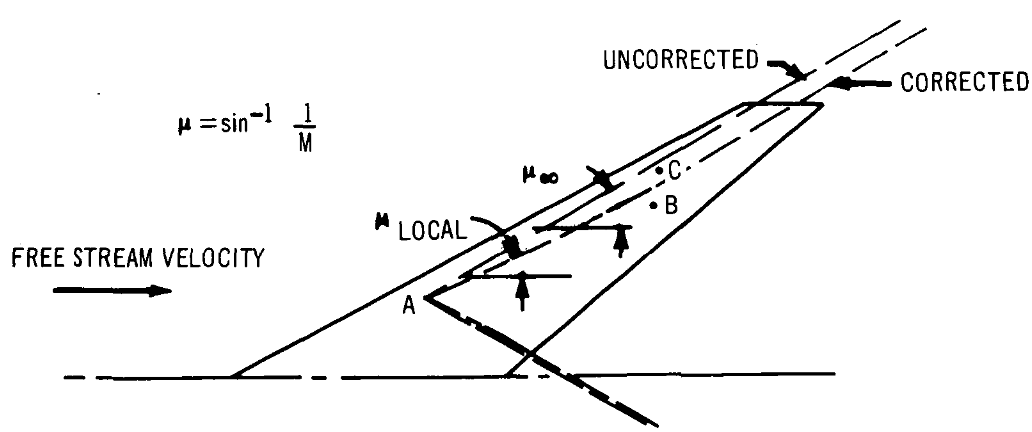
Figure 2 compares the theory with experimental data for a cambered wing and body, in which aeroelastic corrections have been used to pretwist the model wing so that it is untwisted at design load. Even though experimental studies showed shock waves and trailing-edge boundary layer separation, pressure comparisons give a good theoretical accounting of body interference effects.

As a comparison with the untwisted theoretical results, the optimized wing-body pressure distributions are superimposed on the untwisted wing results in figure 3 as dashed lines. One of the more pronounced effects is the improved inboard span loading. A reduction in wing pressure drag of 19 percent was achieved by this optimization and the total wing-body drag reduction of 23 percent showed an even greater overall gain.

SUGGESTIONS FOR FUTURE WORK

Ten suggestions for future work are enumerated below (their order is of no particular significance):

1. Incorporate a Whitham-type correction to the influence lines. —Comparison between linearized theory and experiment shows that the local velocity, rather than the free-stream flow, controls the direction of influence lines. Thus a disturbance field computed for an element on a wing or body has the boundaries of its zone of influence appreciably altered, as sketched below:



In this case point A has an influence on both B and C in the free-stream Mach cone geometry, but point C is not within the corrected influence boundary. Such a correction has a significant effect on the accuracy of wing-body solutions and, consequently, their optimization.

2. Extend program to sonic boom capability.— This suggestion is a logical outgrowth of the Whitham-type flow-field correction in which the procedure is carried to the far field. Results would give the pressure signature as a continuous function of distance from the vehicle without additional simplifying assumptions.

3. Formulate and program a subsonic solution. — All of the geometry programs and some of the aerodynamic functions and program logic can be useful in a linearized subsonic solution. There is firm evidence that, with proper limitations on the aerodynamic functions, continuous solutions through the transonic region may be achieved.

4. Refine body representation. — The method simplifies the body geometry by matching only the body cross-sectional area and centroid location. This ensures proper volume distribution and camber, but neglects noncircular cross-sectional geometry. Multipoles or surface paneling of the body should be investigated for a better representation.

5. Incorporate body and wing nonplanar boundary conditions. — After the body representation is refined, the boundary points should be moved to nonplanar locations on the body surface. Then, to satisfy the physical boundary conditicns, a corresponding change could be made on the wing. This would improve the accuracy of the wing-body geometric optimization.

6. Optimize total wing-body combination. — The program now minimizes drag with wing camber and twist. In most cases it should be possible to improve the design by optimizing the wing and body simultaneously. Secondary constraints on the body could be introduced to preserve reality (for example, prohibit negative volumes).

7. Add nacelle simulation capability. — Another important wing interference problem is that caused by the power plant nacelles. To solve the design problem,

it may be feasible to use the singularities already formulated, or it may be better to introduce others, such as ring vortices.

8. Add wing section design constraints. —Solutions resulting from theoretical design methods very often have undesirable characteristics, such as wing sections that fail to satisfy stringent viscous-flow criteria. When these limitations are known, they can be applied as design constraints and used at the aerodynamicist's discretion. Maximum local velocities, pressure recovery gradients, wing section thickness, etc. can be imposed to make designs more realistic.

9. Extend to include aeroelasticity. —As design procedures improve, wind tunnel and flight conditions must be more accurately represented. Aeroelasticity becomes important for high structural aspect ratio, thin wings, and high dynamic pressures; it is necessary for both design and analysis.

10. Add capability for flow field computation. —The disposition of the elemental singularities to the body and wing surfaces should produce accurate flow field descriptions, even close to these surfaces. Then it may be useful to trace streamlines (from the field vectors), compute tail downwash properties, describe inlet flows, etc.

BASIC DATA APPLICABLE FOR GENERAL USE

One significant product of the aerodynamic theory was the supersonic potential function developed for a constant-pressure surface element at incidence. Former methods of linearized theory neglected this nonplanar character and approximated the effects of incidence, camber, and twist by adding an appropriate cross-flow. The new potential function produces a vortex flow above the incident surface, similar to those observed experimentally on delta wings of low aspect ratio. Thus, a fundamental improvement has been made, and it is highly probable that it may have other important applications.

REFERENCES

1. Woodward, F. A.; Larsen, J. W.: A Method of Optimizing Camber Surfaces for Wing-Body Combinations at Supersonic Speeds — Theory and Application. Boeing Document D6-10741, Part I, September 1965.
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3. Carlson, H. W.: Pressure Distribution at Mach Number 2.05 on a Series of Highly Swept Arrow Wings Employing Various Degrees of Twist and Camber. NASA TN D1264, May 1962.